Planar Retroreflector

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Abstract: We propose a planar retroreflector composed of two cascaded high contrast periodic structures with slowly varying features. One of the high contrast structures focuses the light while the other reflects it as a concave mirror.
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A retroreflector reflects back a significant portion of the input beam along the incident direction and to the light source. There are two main types of retroreflectors: corner cube and cat's eye. Corner cube retroreflectors are composed of three mutually perpendicular reflecting surfaces (similar to the inner surfaces at the corner of a cube). They provide high retroreflection efficiency and wide range of incident angles. For applications in optics and free space optical communications, they are made by reflective coating the outer surfaces of a corner made of glass or other transparent materials. Lower cost implementations are used for making road and night safety signs and include shaping polymers and plastics layers in the form of an array of corner cubes. Cat's eye retroreflectors are composed of a focusing lens and a concave mirror (as shown schematically in Fig. 1(a)). They are often implemented by reflective coating a portion of small glass or plastic beads or micro-spheres. The beads are usually embedded in a thin sheet or paint and are used in retroreflective coatings. Such a retroreflective surface generally shows a limited retroreflection efficiency.

Free space optical communication and optical remote sensing are among the applications of retroreflectors. In free space optical communication, the retroreflector is often integrated with an optical modulator and is a part of a remote transceiver mounted on a satellite or an aircraft. In this case the size, weight, and integrability of the retroreflector with the modulator (which is often fabricated on a flat substrate) are important issues. Corner cube retroreflectors have been used to implement such transceivers, but they account for a major portion of the size and the weight of the transceiver [1]. In another design, cat’s eye retroreflectors have been realized by a combination of a telescopic lens and a flat mirror [2]. Here we propose a retroreflector that can be mass produced using conventional micro-fabrication techniques and binary lithography. The proposed retroreflector has a low profile and weight, is fabricated on a flat substrate, and can be readily integrated with other components such as optical modulators.

A schematic diagram of the proposed retroreflector implementation is shown in Fig. 1(b). The retroreflector consists of a flat lens and a flat mirror separated from each other by a transparent spacer layer. The lens and the mirror are high contrast gratings and are realized by gradually changing the geometrical parameters of a two dimensional periodic structure [3, 4]. The periodic structure is patterned on a layer of material with high refractive index surrounded by lower refractive index materials. Figure 1(c) shows the lens and the mirror realized by gradually changing the diameters of circular silicon posts arranged in a hexagonal lattice. For designing the retroreflector, we considered periodic structures made of silicon posts arranged in a hexagonal lattice and resting on a 5um thick silicon dioxide membrane. To find the phase and amplitude of reflection and transmission coefficients for a plane wave incident normal to such a periodic structure, we performed numerical simulations using the rigorous coupled mode analysis technique. Figure 1(d) shows the transmission amplitude and phase for a periodic structure with the lattice constant of 1μm and post height of 1.3μm as a function of the duty cycle (ratio of the post diameter to the lattice constant) at the design wavelength of $\lambda = 2\mu$m. For the chosen post height, the periodic structure is mostly transmissive and the transmission phase can be controlled by varying the duty cycle between 30% and 70%. By changing the radii of the posts gradually, a structure is obtained whose local transmission phases might be approximated by those of the periodic structure of the same parameters. Using this periodic structure, we designed a parabolic phase mask which focuses the light similar to a convex lens. A similar plot for the reflection amplitude and phase of the same periodic structure but with a different post height of h=0.7μm is plotted in Fig. 1(e). This periodic structure is mostly reflective and the reflection phase spans a full 2π range. As we can see in Fig 1(e), the reflectivity goes down around the duty cycle value of 75%. We excluded the duty cycles close to that range, and designed a reflective phase mask that behaves as a concave mirror with a focal length of $f_m = 20\mu$m. The focal length of the lens $f_l = 40\mu$m is roughly equal to the radius of curvature of the concave mirror. The separation between the lens and the mirror $d = 38.5\mu$m is approximately equal to the focal length of the lens and is adjusted to maximize the optical power reflected back along the incident direction. As shown schematically in FIG. 1 (a), the light is focused by the lens at the mirror’s plane and is reflected back by the mirror along the incident angle.

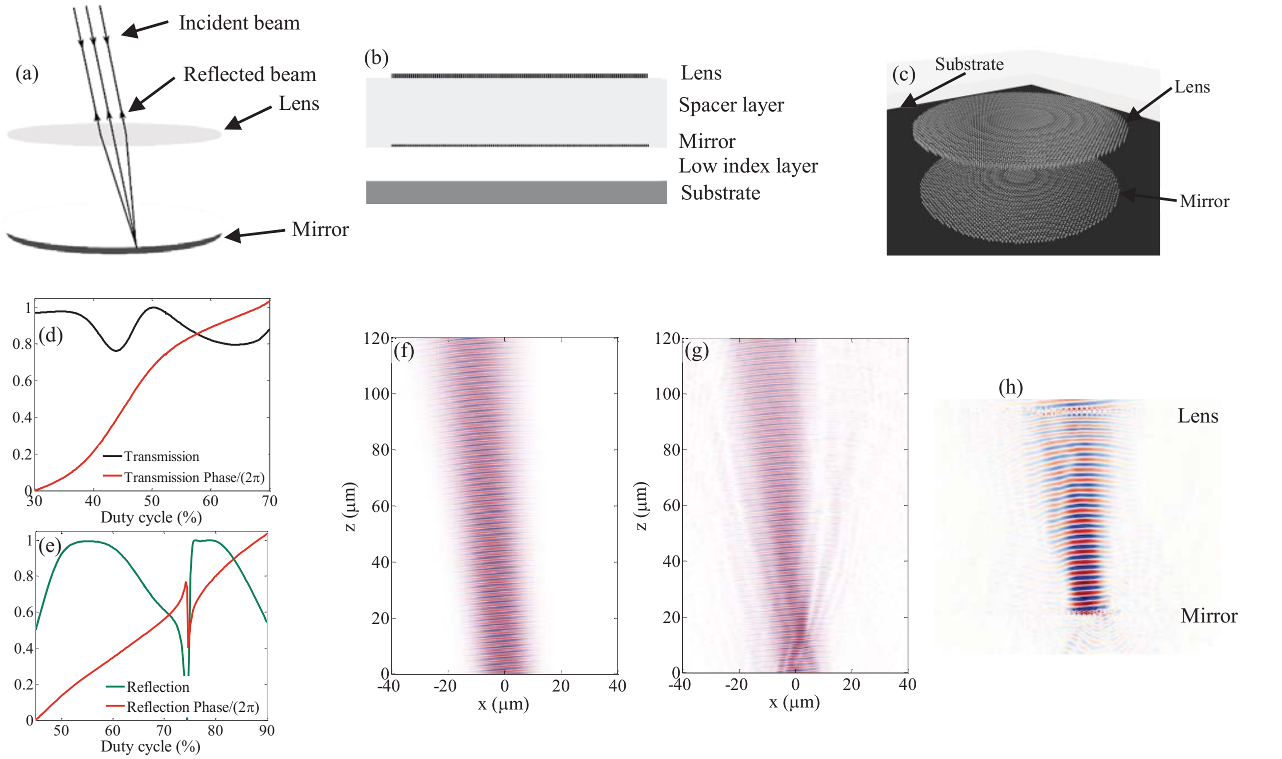

Fig. 1. (a) Schematic illustration of a cat's eye retroreflector composed of a focusing lens and a concave mirror. (b) Side view, and (c) perspective view of the proposed planar implementation of the cat's eye retroreflector using a flat lens and a flat mirror. Both the lens and the mirror are realized by gradually varying radii of circular silicon posts arranged in a hexagonal lattice. (d) Simulated transmission phase and amplitude of the periodic structure used for implementation of the focusing lens. (e) Reflection amplitude and phase of the periodic structure used in realization of the mirror. (f) Simulated electric field of the input and (g) reflected beams of the retroreflector. (h) Electric field in the vicinity of the retroreflector and between the lens and the mirror. The incident field is the Gaussian beam shown in (f).

We performed numerical simulations using the finite difference time domain (FDTD) technique to find the reflected beam when a Gaussian beam is incident at an angle on the retroreflector. The electric field of a Gaussian beam impinging on the retroreflector at the incident angle of 2.5° from the normal direction is sown in Fig. 1(f). The reflected field is calculated using the FDTD simulations, propagated using the plane wave expansion technique, and is depicted in Fig. 1(g). As expected, the reflected beam is directed along the same angle as the incident beam. The total electric field inside the retroreflector is shown in Fig. 1(h). As we can see form this figure, the beam is focused by the lens layer and is reflected back along the same direction by the mirror layer. For this retroreflector, the reflected power along the incident direction is 88% for a beam incident along the normal direction, and is reduced by 3dB when the beam is tilted by ±5° from the normal direction. The reduction of the power is mainly due to the dependence of the mirror efficiency on the incident angle, and it is expected to be improved by optimizing the mirror design.

References

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